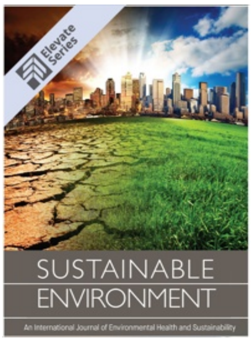

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Compost quality of a peri-urban waste composting facility: A case of Mukono municipality, Uganda

Sarah Kizza-Nkambwe[a], Maxmillan Mpewo[a,b], Junior Senyonga Kasima[c,d] and Kheria Mfuranzima[d]

[a]Faculty of Engineering and Environment, Uganda Christian University, Mukono, Uganda; [b]Uganda National Bureau of Standards, Kampala, Uganda; [c]Faculty of Agriculture and Environment, Gulu University, Gulu, Uganda; [d]National Agricultural Research Laboratories, Kawanda, Kampala, Uganda

ABSTRACT

Effective management of windrow-based composting technology in developing cities is a major challenge, especially for municipal authorities mandated to offer these services. Poorly managed waste composting systems could affect the quality of compost and cause complex environmental impacts. The aim of this study was to assess the quality of compost of a waste composting facility in Mukono municipality, central Uganda. Mature compost samples were collected from windrows in the waste composting facility and the samples analyzed for physicochemical parameters (temperature, pH, moisture content, organic matter, total nitrogen, total phosphorus, and potassium) and for heavy metals (lead, cadmium, copper) and metalloids (arsenic). To assess the quality of the compost, the analyzed results of the samples were compared with common ranges for compost quality. Concentration of heavy metals ranged between 0.01 mg/l (cadmium) and 0.4 mg/l (copper). Except for alkaline pH (9.1), which was higher than the recommended range for mature compost quality, all physicochemical parameters and heavy metals were within common ranges for compost quality. Moisture content and pH correlated with heavy metals, 0.75 and 0.78, respectively. Mean total nitrogen and phosphorus were 0.8% and 0.4%, respectively, while organic matter was 21.7% and potassium 0.3%. Compost quality did not differ between seasons ($P = 0.05$). Based on the study results, continuous investigative research is recommended to safeguard the compost quality.

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KEY WORDS
heavy metals; mature compost; Mukono municipality; waste management; windrows

1. Introduction

The continued increase in population in the different urban centres of Uganda has resulted in escalating volumes of wastes generated in these areas (Kabasiita et al., 2021; Madinah & Hanifah, 2019). This is not withstanding the poor waste management systems in the urban areas of Uganda, which threaten the environmental safety and health of urban dwellers (Madinah & Hanifah, 2019; Tibihika et al., 2021). In her mandate to ensure environmental sustainability, the National Environmental Management Authority (NEMA) started a municipal solid waste management initiative in different municipalities across the country (Lederer et al., 2015). This was employed as a strategy to reduce the environmental effects from poor waste management in urban centres. To sustain the operations of these sites, each of the respective municipalities was required to generate income through the sale of compost to farmers (Kabasiita et al., 2021). This has been implemented, although limited information exists, especially on the quality attributes of the compost from these sites, since they accommodate wastes from diverse sources. For purposes of food safety, information on the physiochemical properties of such compost is essential, which calls for regular quality assessments. This will also enrich NEMA's database to guide policy on composting operations at municipal waste management sites.

Sustainable management of municipal solid waste (MSW) is a critical issue around the world (Roy et al., 2021). Waste composting investigative studies provide valuable data relevant to compost quality standards, management and utilization requirements. Quality standards are needed for maintaining and improving the intrinsic worth of composts and promoting their utilization. Unlike several European countries that have adopted specific compost quality standards and guidelines (Khoshnevisan et al., 2021), there are no known published standards specific to compost quality in Uganda, and instead, there are general compost quality guidelines

CONTACT Junior Senyonga kasi95js@gmail.com Faculty of Agriculture and Environment, Gulu University, P.O Box 166, Gulu, Uganda; National Agricultural Research Laboratories, Kawanda, P.O Box 7065, Kampala, Gulu Uganda

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with implied standards (NEMA, 2020). The concept of establishing standards specific to compost could promote quality criteria and indirectly enhance growth of compost markets and utilization. Complying with the technical specifications of compost production is of high importance not only for environmental protection but also for increasing the productivity and promotion of compost use by farmers in agriculture (Al-Sari et al., 2018). Utilization of compost enhances nutrient cycling and builds the soil's organic nitrogen pool which promotes environmental sustainability. One key approach to manage and maintain compost quality is regular compost tests and increased awareness of the health impacts of contaminated compost. The current study derives its essence from this information void to contribute to the generation of data for use in maintaining the quality of compost from Mukono municipal waste management site. The site was particularly selected since it is surrounded by farming communities, an indication that the compost site is of great benefit to the farming communities. Presently, at least 63% of Mukono municipal wastes are compostable (Figure 1); annually, 3214.8 metric tons of wastes are generated, and this has been projected to triple in the next 5 years (Omara et al., 2019) due to rapid population and economic growth. Despite various strategies by the Mukono Municipal authorities to promote and encourage waste composting, there is little information about the quality of the compost. This study reports findings of quality of compost of the municipal's waste composting facility.

2. Materials and methods

2.1. Study area

The waste composting facility is located in Mukono district, in the central region of Uganda (Figure 2), between 0.3533° N, 32.7553° E and elevation of 1246 m above sea level. The area has a tropical climate characterized by a mean annual rainfall range between 1,750 and 2,000 mm. The average annual temperature is 21.9°C and relative humidity ranges from 53% to 89% (Kirenga et al., 2015) with precipitation throughout the year, even during the driest months. The soils are dominantly ferralitic. The area is flat with many undulations; 75% of the land is less than 600 in slope. The vegetation has been described as secondary vegetation and shrubs (Bukenya et al., 2009) as a result of periodic bush burning and cultivation. The site borders with Katikolo hill to the east; to the far west and south is Katikolo wetland which forms a buffer zone for Lake Victoria. The composting facility's design capacity is 70 tons per day (TPD); the composting area (windrow bays) is roofed (Figure 3a-d). The major economic activities of the people of the study area are agricultural related.

2.2. Samples and sampling procedure

At the time of this study, active composting of wastes had been practiced for a period of 4 years; the waste composting facility is based on windrows technology. The windrows are concreted such that compost does not come in contact with the ground. Compost samples were collected from within the final windrow where the compost was 12 weeks old; had reached complete composting and thus known to be mature compost. The samples were analysed in the laboratory for physicochemical parameters (temperature, pH, moisture content, organic matter, total nitrogen, total phosphorus, and potassium) and also for heavy metals (lead, cadmium, copper) and metalloid (arsenic) concentrations.

All sampling points and samples collected for analyses were representative of the mature compost

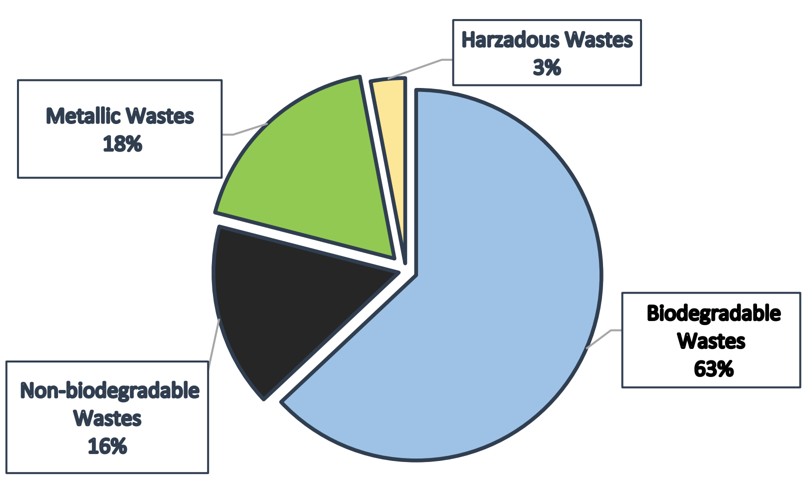

Figure 1. Categories of wastes generated in the study area (Modified from Omara et al., 2019).

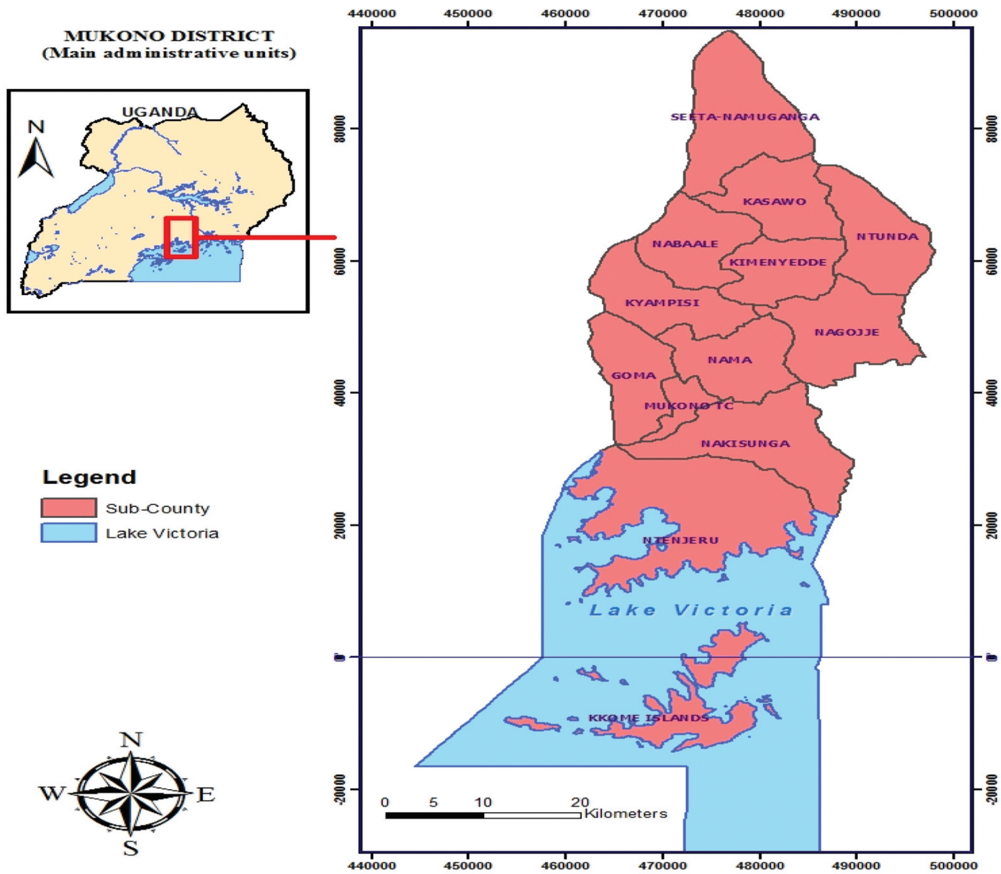

Figure 2. Map of Uganda showing study area of Mukono municipality.

of the facility as a whole. Using a hand trowel, compost samples were taken at 30 cm depth at five randomly located points from within the windrow. Depth of 30 cm was considered suitable to account for the distribution of moisture content and the temperature within the pile. Samples from the five points were bulked and mixed to obtain a composite sample from which 300 g was obtained for laboratory analysis. Samples for testing all parameters were collected in clean self-sealing soil sampling bags. Compost sampling and analysis were done in both the dry and wet seasons for comparative purposes. A total of 20 samples were collected for analysis, half of which represent the respective wet or dry seasons. Samples were kept at 4°C and transported to the laboratory within 5 hours after collection.

2.3. Compost quality determination

2.3.1. Physicochemical parameters

Moisture content, pH, and temperature were determined in situ using a four-way analyser (1880 Rapid test) and a digital thermometer (temperature probes). In situ determination of the above was important because these parameters are highly variable in compost and dependent on local environmental conditions. Organic Matter (OM %) content was determined using the Walkley-Black wet combustion method (USDA, 1996; Van Reeuwijk, 1993). Total Nitrogen (TN%) was determined on the basis of extraction procedures developed by Okalebo et al. (2002); the aliquot from the digest was distilled in boric acid and titrated with 0.1 N HCl. Total phosphorus was estimated by the same procedure, and the aliquot from the digest was complexed to a blue colour by ascorbic acid and absorbance read from a spectrometer. Similarly, the aliquot from the digest was read from a flame photometer against K standards to determine potassium concentrations (Okalebo et al., 2002). Each sample was analysed in duplicate.

2.3.2. Heavy metals and metalloids

Samples prepared for element analysis were ground to fine-sized particles (particle size <0.053 mm). Heavy metal and metalloid concentrations were determined according to routine testing procedures (APHA/AWWA/WEF, 1998); atomic absorption spectrometer

(a): Compost raw materials in windrow bays

(b): Pre-sorted waste composition

(c): Compost raw materials composition and

(d): Mature compost

Figure 3. (a) Compost raw materials in windrow bays. (b) Pre-sorted waste composition. (c) Compost raw materials composition and sorting. (d) Mature compost.

(AAS), ICP—MS (inductively coupled plasma-mass spectrometer) and GFAAS (graphite furnace atomic absorption spectrometry).

3. Results and discussion

Presently, the composting process at the facility is aerobic, and no additional nutrients are added during the composting process. Since aerobic composting is a biological process and subject to natural limitations, the composting raw materials at the facility could be a factor in influencing the results of the mineral contents of this study.

3.1. Physicochemical compost quality

The pH of the compost was 9.1 during the dry season and 9 during the wet season (Table 1). This is above the 7–8 range (Sullivan et al., 2003) which is the optimal range for microbial activity in compost, and also beyond the international standards 5.5–7.0 (Brinton, 2000). Nonetheless, the pH of the compost was within the range of the local standards by Uganda National Bureau of Standards (US 1584:2017 Organic fertilizer—Specification). Since the activity of composting microbes is pH dependent (Jalalipour et al., 2020), deviations from the optimal range could alter the quality of the final compost. The pH values obtained in the

Table 1. Compost quality analytical results (mean values)

Parameter	Dry season	Wet season	Compost quality common range*	US 1584:2017**
pH	9.1	9.0	7–8	6–10
Temperature (°C)	46.7	46.1	45–50°C	-
Moisture content (%)	46	47.4	<60%	30–35%
Organic matter (%)	21.6	23.0	32–43%	-
Total nitrogen (%)	0.8	1.0	.7–1.5%	1
Total phosphorus (%)	0.5	0.5	.3–.6%	-
Potassium (%)	0.3	0.5	.2–.5%	-
Lead (mg/kg)	0.03	0.02	0.1 mg/l	100 (mg/kg)
Cadmium (mg/kg)	0.01	0.01	0.1 mg/l	5 (mg/kg)
Copper (mg/kg)	0.4	0.5	1.0 mg/l	300 (mg/kg)
Arsenic (mg/kg)	BDL[†]	BDL[†]	0.2mg/l	10 (mg/kg)

* Sullivan et al. (2003); †Below detectable levels; ** UNBS Standard; US 1584:2017 Organic fertilizer—Specification.

current study are higher than the averages (8.02 and 7.24) obtained in the municipal solid waste composts from different cities in India (Rawat et al., 2013; Vyas, 2011).

Mean temperature of 46.7°C is within common ranges for compost quality, even though higher temperatures (about 60°C) could also present a suitable option for improvement of composting since sanitization of compost (through destruction of pathogenic organisms and weed seeds) is essential. Temperatures of compost are reported to vary with raw material being composted. Our findings are depictive of a mixture of raw materials being composted as Mamo et al. (2021) reported lower temperatures with sole compost raw materials but comparable temperatures with mixed materials. Such high temperatures in addition to alkaline pH could, however, lead to increased ammonia emissions (Agyarko-Mintah et al., 2017) while low temperatures (<40°C) slow the composting rate. This could explain the results of the elevated total nitrogen between the wet and dry seasons. Moisture content (MC) of 46% indicates adequate quantity of water present in compost that is essential for microbial activity. This moisture content is commensurate with the MC reported by Mamo et al. (2021), but far beyond the national standard (35%) by UNBS. Nonetheless, moisture content for aerobic composting varies with materials used. Unsuitable temperature, pH, and moisture content in composting are responsible for obtaining compost with a low agronomical quality (Tibu et al., 2019).

Mean values for total nitrogen and total phosphorus were 0.8% and 0.4%, respectively, while organic matter (OM) was 21.7% and potassium, 0.3%. OM is useful in estimating the age of compost and results of 21.7% OM suggests that the compost was not fully matured despite the four-year composting period at the facility. It is also important to note that environmental conditions directly influence microbial activity and the rate of organic matter degradation during the composting process (Li et al., 2021) which could have been the case in this study. Desirable optimal amounts of OM, potassium, total nitrogen, and phosphorus derived from compost provide positive impacts on soil quality acting as effective organic fertilizer which favour higher exploitation of soil environment by plants. Where the nutrient contents are inappropriately high, nutrient leaching, volatilisation, and consequent pollution of the environment may ensue. Insufficient nutrient levels below optimal amounts lead to reduced supply and availability of nutrient sources for plants where supplemental N, P, and K fertilization would be required.

3.2. Element concentration

Concentration of heavy metals ranged between 0.001 mg/l (cadmium) and 0.4 mg/l (copper). While lead was 0.03 mg/l, arsenic (metalloid) concentrations were below detectable levels (Table 1). Mean values for heavy metal concentrations were within common ranges for compost quality (Rahman et al., 2020), and the national standard, US 1584:2017, and international standards (Vyas, 2011). The heavy metal concentrations of the sampled compost are all through lower than that reported around the Sunyani composting facility in Ghana (Agbeshie et al., 2020). Even though this is the case, the presence of heavy metals is of concern since this indicates contaminated compost. Relative to the age of the composting facility, various interrelated factors indicate that the heavy metal contamination is likely to increase with time. For instance, a previous study (Bumba, 2011) reported that 80% of the facility wastes are of domestic and commercial origin; both sources make up 48% of the wastes identified within the composting raw materials at the facility. Focus on waste segregation at source for successful composting is also not emphasized such that all the generated wastes are disposed of in combination with other wastes. Additionally, at the time of this study, standard methods of sorting wastes before the composting process were not being carried out at the facility. However, unconfirmed sources of information suggested that waste sorting had been a common practice at the facility but had to be suspended for reasons related to funds. Poor handling standards would most likely result in increased concentrations of heavy metals and other undesirable ingredients in compost. Furthermore, the increasing population and related affluence reports (UBOS, 2012) composition and type of wastes (Ojok et al., 2013; Omara et al., 2019) have led to an increase in generation of wastes in the study area. Considering the above factors, a higher concentration of heavy metals and metalloids is likely to occur since 60% of these generated wastes (Bumba, 2011) end up at the composting facility. It is also important to note that heavy metals can be ubiquitously found in the environment, consequently in the quality of composting raw material and in the mature compost as the end product.

Table 2. Compost quality results summary statistics

	Dry season	Wet season
Mean	12.54	12.80
Variance	363.76	371.61
Standard error	6.031	6.09
Standard deviation	19.07	19.27
Skewness	1.34	1.31
Confidence level	13.64	13.79
Pooled variance	367.69	-
df	18	-
t stat	−0.030	-
t Critical two-tail	2.10	-

3.3. Seasonal compost quality

Compost quality did not differ between seasons ($P = 0.05$) (Table 2). Results of the dry season's high temperatures entail higher losses through OM mineralisation when the surface of compost in windrows gets exposed to desiccation. Temperature and moisture content regulate nitrification, volatilisation, denitrification, and mineralisation of OM by influencing microbial processes (Kizza & Areola, 2010). Seasonal trends of the generally elevated values for some parameters in wet season in comparison with dry season were expected and point to variations in nutrient loss in which higher wet season values suggest possible translocation processes during the wet season. Even though nitrogen in composted manure has been stabilized and is less likely to leach, the seasonal trends are indicative of the extent to which the wet-season humid environment and consequential leaching can reduce the magnitude of inter-seasonal variations by undermining nutrient accumulation.

4. Conclusion

Results of this study show that the quality of compost of Mukono municipality, central Uganda, varied only within acceptable limits. Except for alkaline pH of 9.1 which was higher than the recommended range for mature compost quality (though within national standards limits), all physicochemical parameters and heavy metals and metalloid tested were within common ranges for compost quality at international standards. However, there is a potential for build-up of heavy metals and the compost quality needs to be continuously investigated to determine the source of contamination. Our study provides a basis to recommend more management efforts in safeguarding the compost quality given the increase in level of urbanization and population growth of Mukono municipality. In addition, sorting of wastes prior to composting should be done at the facility as a quality control strategy to ensure that compost with acceptable physiochemical properties is obtained. This will reduce the threat of introduction of heavy metals and metalloids into the food chain which would threaten the health of the population that consumes food from fields enriched with such compost.

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ORCID

Junior Senyonga Kasima http://orcid.org/0000-0003-1498-0823

Declaration of conflicting interests

The authors have no conflicts of interest to declare regarding the publication of this paper. This research was shared in a poster presentation at a local workshop. Poster presentation information is unpublished.

Data availability statement

All data concerning this work has been availed within the article

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